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This note records some of the authors' experiences at The RAND Corporation and the California Institute of Technology in developing curricula for training management scientists. Professors Burton Klein and Hallett Smith of the Humanities Department, California Institute of Technology, invited us to prepare and present courses in Management Science during the Winter and Spring Quarters of 1970. Our experience in recruiting staff for RAND's Management Sciences Department had left us frustrated. The professional interests of top-flight graduates of the best Operations Research and Management Science curricula in the country did not mesh easily with the problems that RAND's Management Sciences Department finds it necessary to address. We found many Operations Research graduates to be overly trained in rather narrow quantitative methodology, and uninterested in concentrating attention on more complex, less quantitative problems. At the same time we encountered many people eager to work on management and organizational problems, but without any quantitative or analytical background. They, too, are generally unsuited to the tasks RAND faces. The authors were therefore eager to develop a new curriculum to produce analysts skilled in methodology from students interested in applied work.

We interpret Management Science at RAND as having to do with the problems of managers and management. These may include determining the objectives and overall strategy of organizations, specifying basic organizational and procedural frameworks within which objectives can be pursued, and conceiving and developing information and control systems that allow managers to keep on track toward desired goals or objectives. Our management science work applies equally well to socially-oriented

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public agencies as to process-oriented industries. Examples of such work are found in our health and housing studies for New York City and in our resource management and program planning work for the Department of Defense.

Our experience has indicated some basic requirements for a good practicing management scientist. He must have the ability to describe and then construct abstract conceptual models of complex phenomena. As basic academic requirements he must be conversant with modern mathematical and statistical reasoning, and possess sufficient computer knowledge to be able to lay out in a systematic fashion the tasks necessary to solve a complex problem.

It appears to help if a management scientist has had some exposure to policy making and organizations, and has some knowledge of the policy issues in the field in which he is going to work. A certain amount of self confidence is necessary to allow him to tackle problem areas in which others have invested considerably more time and may have more apparent wisdom. He must also possess a certain combination of daring, intuition, and maturity, which allow him to draw conclusions and make recommendations on the basis of the undoubtedly incomplete data with which he must work. Above all he must be curious.

Traditional Operations Research curricula provide students with the necessary scientific, mathematical, and computer abilities, but do not expose them to the way actual management policies are made, nor provide them with the ability to decide when inferences can be made. Most important, Ph.D. students appear to be oriented toward extensions of methodology rather than toward analysis of problems.

Our RAND experience further indicates that the individual Operations Researcher uses very few of his formal tools. In fact, he almost always selects one approach and uses it on every new problem he confronts. We have never seen an important problem-solving effort fail because the proper methodology with which to address it was not available. It is more common for the problem-solving researcher to learn new techniques to deal with his current problem because he cannot locate the necessary expert.

In view of our RAND experience, we hypothesized that we could take Cal Tech's extraordinarily well-trained engineers and scientists, expose

them to good examples of management science and operations research, and produce critical, sophisticated consumers of analysis, who were also sufficiently competent to do their own analysis. We believe we succeeded.

During the first ten-week quarter our course met for three hours each week. Classroom hours were divided equally between presentations of methodology and summaries of projects selected to indicate how that methodology was used in actual problems. The lectures and cases are shown below.

1. Survey of Management Science and Systems Analysis
2. Economics of Engineering Decisions
3. Economics of Macro Systems
4. RAND Case Study: Government Operations in the Philippine Islands
5. Resource Analysis and Program Budgeting
6. Mathematical Programming

7., 8. RAND Case Study: Development Strategies for Air Transportation in the New York Region, 1970-1980 (2 lectures)

9. RAND Case Study: Analysis of Urban Housing Policies
10. RAND Case Study: Analysis of Urban Police Activities
11. Decision Theory
12. RAND Case Study: Decision Theory in Medical Diagnosis
13. Statistical Methods in Systems Analysis
14. RAND Case Study: Mathematical Models in the Analysis of Poverty
15. Computer Simulation of Micro Systems
16. Computer Simulation of Macro Systems
17. Introduction to Management Systems
18. Management Systems and Information Systems
19. Limitations of Systems Analysis
20. Course Summary

The RAND cases were presented and discussed by a RAND staff member, and the presentation of these cases along with the lectures on methodology made the students much more demanding as to the relevance and utility and particular techniques than usual in first year graduate students.

The second course was built around student projects. The students divided themselves into groups which met once a week for about 3 hours.

At the start of the quarter few students had any specific areas or ideas of their own on which to work. To assist in project selection, we listed a number of areas from which the six topics below were finally selected.

- Delays in Criminal Justice and Court Proceedings,
- Parking Problems in Urban Transportation,
- Starting New Enterprises Based on High Technology,
- Supply and Demand for Scientifically Trained Manpower,
- Computer aided Job Scheduling in a Foundry, and
- Decision Methodology in Opening a New Insurance Office.

Each group was to conduct research on its project, to present to the class at least one interim briefing on their progress, and to submit written and verbal final reports on their work. We held weekly discussions with each individual group on the direction and progress of projects.

At the start of the quarter some students proposed quite narrow problems which they wanted to explore as individuals during the course. We rejected these proposals as inappropriate for the type of course we were developing, and urged them to join one of the existing group projects. Some students joined the other groups and some left the class. About half of the students completing the first quarter remained beyond the project definition stage of the second quarter.

The groups made presentations to define their projects to the class during the second and third weeks. At this time the groups displayed no more than layman's knowledge of their subject areas. In fact, they were all quite vague as to project objectives, approaches, and achievable results. For the next three weeks the instructors split up and worked with each group in individual sessions of about an hour a week. We assisted in defining very specific questions which they would address, their methodology, data requirements, and the final objectives of their projects. During the last three class sessions each of the six groups verbally presented project results to an audience which, in addition to the class members, included people selected on the basis of subject knowledge and instructed to be critical. In addition to presenting their own project, each project group was asked to criticize one of the other projects.

We were quite pleasantly surprised at the final results. Students of varied backgrounds had organized themselves into research groups. Each project had succeeded in accomplishing several objectives. Through hectic library research the students had rapidly acquainted themselves with the state of knowledge in their particular problem area and had selected a very specific problem. They had aggessively located relevant data sources in the public agencies of surrounding communities and had drawn some conclusions from analysis of that data and from contact with the agencies with which they had worked.

We have briefly summarized the nature of each of the six projects. Two mathematicians were interested in criminal justice. Through a visit to the Los Angeles County Courthouse and discussion with various offices, they obtained an overview of existing court problems, and after discussion with the Public Defender's office they chose court delay for further study. They catalogued a large number of reasons for court delay, and narrowed in further on "continuances" as one of the prime causes of delay. They then were able to scrape together data which permitted them to look at the number of continuances per case, the amount of delay per case, and the way those measures have changed over time. As is familiar to practitioners of OR/MS, their final report presents recommendations on the types of data systems necessary to facilitate further research in this area of court practice.

Several engineering undergraduates, initially interested in urban transportation, elected to study traffic and parking problems at Cal Tech. They participated with Cal Tech's own traffic committee and became quite knowledgeable about Cal Tech's problems in providing adequate parking capacity during the next ten to fifteen year period. They developed and presented criteria for measuring the desirability and impact of different parking and traffic plans.

A physicist, a chemist, and several engineers formed a group to select a technology with which they were familiar -- membranes which allow efficient gaseous diffusion -- and developed a useful commercial product in the medical area from this technology. They explored the management, financing, and production problems of establishing a new company to produce and market their product, and they proposed and analyzed various strategies for proceeding with their new product.

One mechanical engineer with no O.R. background previous to this course had, during one summer's employment, been faced with a complex scheduling problem in a foundry. This young engineer drew together a group with the initial objective of designing a computer-assisted algorithm to handle the foundry scheduling problem. We initially opposed this project because of its narrow, "classical" aura. However, the enthusiasm of the group caused us to allow its continuation, and the surprising and valuable result was, rather than an algorithm, the design and cost analysis of an information system which could be used by the foundry personnel to schedule production of the custom-made castings.

The fifth group selected a topic then very relevant in southern California -- the supply and lack of demand for scientists and engineers. They collected, examined, and discussed various policy options which federal and state governments and large universities have in alleviating the problems caused by the current oversupply in many scientific specialties. While initially oriented toward a statistical study, the group rapidly became knowledgeable in the institutional problems a university faces in planning and initiating major changes in its curricula.

The final group elected to study the decisions large firms make in opening branch offices. They selected one insurance company and used its branch offices to obtain data with which to examine its branch office decisions. They finally examined and discussed various sales forecasting techniques -- the most critical variable in opening new branch offices.

We have drawn several conclusions from this experiment at Cal Tech. First, our students appeared to respond extremely well to the pressure of the second quarter. Most of them became highly interested and involved in a problem area with which they had been ignorant previous to the course. As the weeks passed, and they argued with our critical comments and interacted with the realities of public and private agencies, they became much more sophisticated in understanding how policy is actually made, much more aware of the knowledge existing in their policy area, and more assured in estimating conclusions that

could be drawn from the data available in their area. They also became quite aggressive in asking penetrating and relevant questions when other groups presented their analyses.

A great deal of their achievement was simply staying with the analysis process -- the process of problem formulation and reformulation. But the students were also able to develop skills in the specific methodologies when that became necessary.

We now hypothesize that policy analysts or practicing management scientists can be trained by taking students with solid quantitative or scientific backgrounds and immersing them in a problem area with experienced guidance. We think that significant and useful change appears to take place as they proceed step by step through an actual analysis, asking questions, and receiving rapid feedback.

Since top level management problems and policy analyses are not dealt with systematically by any academic discipline, and since policy, organizational, and management issues arise with all of RAND's clients, we have sought to develop staff to study such issues. This experience at Cal Tech is an instance in our continuing attempts.